15 p.

Title: THE SPACE DISTRIBUTION OF TRAPPED FISSION DEBRIS FROM THE HIGH ALTITUDE NUCLEAR TEST OF JULY 9, 1962*

N64-18428

CODE-1

(NASA CR-53592) OTS:

by

Raymond G. D'Arcy +

Enrico Fermi ~~Institute~~ for ~~Nuclear Studies~~

University of Chicago U., Ill.

Chicago 37, Illinois

0591032

and

Stirling A. Colgate

Lawrence Radiation Laboratory [1962] 15 p refs

Livermore, California

double codes

0520742

UNPUBLISHED PRELIMINARY DATA

conf.

A paper delivered (Presented) at the Joint NASA-DASA ~~Symposium~~ on the Artificial Radiation Belt, held at the Goddard Space Flight Center, Greenbelt, Md., Maryland on Sept. 10-11, 1962.

*This research was supported in part by the U. S. Air Force Geophysics Research Directorate under Contract No. AF 19 (604-4554) and the National Aeronautics and Space Administration under Grant No. NsG 179-61, and by the Atomic Energy Commission. (NASA)

+Now at the Lawrence Radiation Laboratory, Livermore, California.

An experiment has been performed to measure the absolute quantity and extent of the fission product debris in the southern conjugate area from the July 9, 1962 high altitude nuclear test. The auroral effects from the Teak, Orange, and Argus tests[1,2] at the conjugate points indicated that an intense flux of beta particles was guided to the conjugate areas. However, the fission debris deposition at a conjugate point, a far more complex phenomenon, has never been experimentally observed.

Since the fission product debris was expected to emit a sufficient flux of γ-rays to be detectable at aircraft altitudes for several hours after the detonation, a mapping of the fission product debris in the southern hemisphere was expected to yield new information concerning the debris distribution in space at that time when the debris became trapped by the earth's magnetic field.

An airborne γ-ray spectrometer (which had been constructed by Dr. Stirling Colgate of the University of California Lawrence Radiation Laboratory, Livermore, California, and Dr. Raymond D'Arcy of the Enrico Fermi Institute for Nuclear Studies, the University of Chicago for the purpose of studying secondary γ-rays from auroral and solar protons in the polar regions) was used for this experiment. This instrument consists essentially of a horizontal 3" x 3" Na I cylindrical γ-ray detector, surrounded everywhere except at one end by a 3/8" thick plastic anticoincidence scintillator cup, for reducing charged particle counting background. The phototube pulses from the NaI detector are sorted by energy into 50 or 100 channels by a transistorized laboratory model RIDL pulse height analyzer. In operation this equipment stores pulses for a preset interval, prints and punches out the spectrum and time on paper tape, clears itself and automatically repeats the cycle.

This equipment was installed aboard a KC-135 aircraft operated by Cambridge Air Force Research Center for upper atmosphere radio propagation and radiation studies (Project 6.10) under the scientific direction of Dr. George Gassmann. A two channel γ-ray recorder assembled by the American Science and Engineering Corporation was also operated aboard this aircraft.

The flight pattern flown during the event is shown in Fig. 1. The KC-135 dumped sufficient fuel immediately before blast time to attain an altitude of 43,000 feet. The rest of the mission was flown at this altitude. The east-west pattern flown for an hour and twenty minutes was intended to check on east-west debris motions either from upper atmospheric winds or continued deposition of trapped fission products. The lower energy limit of radiation accepted by the spectrometer was adjusted several times to the lowest value consistent with freedom from large dead time effects. The scale factor was also varied so as to cover the maximum energy range of the excess γ-radiation.

Beginning a few seconds after the detonation, the γ-ray intensity rose during about 20 seconds to a peak value, then began to decline. The east-west passes showed no apparent westerly drift, indicating that most of the debris detected traversed only a few trapped orbits and was relatively undisturbed by upper altitude winds for at least 1-1/2 hours after stopping in the upper atmosphere. Preliminary contours of the γ-radiation normalized according to an assumed $t^{-1.2}$ time decay[3] prepared by R. Giacconi and J. Carpenter of American Science and Engineering from the lower channel of their γ-ray recorder (energy loss above 0.45 Mev) are indicated in Fig. 1. They suggest an extremely steep gradient of debris density on the northern edge and a very diffuse gradient on the southern edge of the flight path.

The spectral results after a background subtraction, normalized to 100 seconds after the detonation by the $t^{-1.2}$ law at early times show a markedly flat energy distribution extending to 12.5 Mev (see Figs. 2, 3 and 4). Within minutes the energy spectrum steepens to the distribution expected from a fission spectrum at 43,000 feet (see Fig. 5). A plot of the excess 10-11 Mev γ-rays fits a 22 second and 55 second decay component (see Fig. 6) rather than a $t^{-1.2}$ decay. Thus it is concluded that these are 10.8 Mev γ-rays from the N_{14} (n,γ) capture[4] of the thermalized 250-650 kev delayed neutrons emitted through Br_{87} -Br^{88} and I_{137} nuclei, resulting from several fast decay chains in fission products[3]. The early intensity normalized according to $t^{-1.2}$, indicates a peak debris density at approximately 15 degrees south latitude and 178 degrees west longitude. Preliminary computations on the basis of these 10.8 Mev neutron-capture γ-rays (see Appendix I) yield a preliminary estimate of 9×10^{10} fission products per square centimeter at Point A (see Fig. 1) and 45 percent of the total debris in the southern conjugate area covered by the flight, assuming one megaton of U_{235} fission products and a symmetrical east-west debris distribution. Taking into account more accurate yields of Br_{87} and I_{137} is not expected to change this estimate by more than a factor of 2. The attenuation of γ-rays produced by neutron capture at various depths is at this point the greater source of inaccuracy, although subject to a more rigorous calculation.

It has been observed[7,8] that a substantial flux of high energy electrons was added to the earth's radiation belts by the July 9 nuclear test. High intensities of these particles have been observed to be trapped with long life-times at equatorial altitudes above 1000 km. Since direct injection of these electrons by β-decay of fission products is the most feasible method of their introduction into high altitude trapped orbits, the spatial distribution of the decaying fission products at early times becomes a subject of considerable interest.

There has been developed, for the purpose of comparing trapped radiation measurements at differing locations, a coordinate system[9] which includes a parameter L, which is constant within approximately 1 percent along a line of magnetic force (as measured by a trapped radiation peak), and which represents for a dipole field the distance (in units of earth radius) from the center of the dipole. A multi-term harmonic expansion of the geomagnetic field is usually used to compute L-values at low altitudes.

The L-value has been calculated for a number of field lines which reach an altitude of 100 km in the southern conjugate region of interest, using the 512 term expansion[10] of Jensen and Whittaker. Interpolations have been made between these field lines. Thus, a series of L-values at 100 km altitude has been plotted in Fig. 1.

According to the observations of Van Allen,[7] an intensity peak at an L-value of 1.13 was noted over Johnston Island within an hour and a half of the detonation. The intensity peak at point A in the southern conjugate region a few minutes after H-hour is seen to correspond to an L-value of 1.10 if the fission products are assumed to stop at an altitude of 100 km. On the assumption of an average stopping altitude of 200 km, the L-values of this peak would coincide with that noted by Van Allen, and would better agree with the L-value expected for the center of the fission product distribution. A 200 km stopping altitude for the fission products at this longitude also agrees fairly well with preliminary results of radio-sounder measurements made at shortly later times from the same aircraft. At these latitudes an upwards shift of 100 km in altitude along the magnetic field lines is the equivalent of a 1-1/4 to 1-1/2 degree north-ward shift of each line of constant L-value.

Using these 200 km L-values as an ordinate, the relative debris density may be plotted as a function of L (see Fig. 7). This profile should correspond fairly well with the altitude distribution of ionized fission products at the time of their trapping by the geomagnetic field. To unfold a source function for the trapped β-rays, a time history of the motion of these fission products must be assumed, since a substantial flux of electrons could have been injected while the debris was still "jetting" across the field lines. It should be noted that debris deposited in the southern conjugate area becomes completely ineffective for the injection of long duration trapped electrons, since the field configuration in this region is such[10] that trapped radiation mirrors several hundred kilometers lower in the northern conjugate area.

APPENDIX I

We expect a small fraction of the fission debris decay chain to emit delayed neutron groups. The two delayed neutron groups observable after 50 seconds are as follows (Table I)[3]:

TABLE I

Precursor Isotope	Time Constant (Sec)	Neutron Energy (kev)	Fraction (percent) n/fission
Br_{87}	55 sec	250 kev	0.063
I_{137}, Br_{88}	22 sec	450 kev	0.35

Approximately half of these neutrons will escape into space, and half will thermalize in the atmosphere, to be absorbed largely by the processes $N_{14}(n\ p)\ C_{14}$ and $N_{14}\ (n,\gamma)$ with thermal cross sections 1.76[5] and 0.08 barns respectively. Also 11 percent of these $N_{14}\ (n,\gamma)$ captures will result in an isotropically emitted 10.8 Mev γ-ray.[4] Therefore, the flux of 10.8 Mev γ-rays near the top of the atmosphere is a fraction .0055 of the incident downward flux of neutrons. Since the absorption length of 10.8 Mev γ-rays in air is (50 g/cm^2) and the measurement was taken at an atmospheric depth of 165 g/cm^2 (43,000 feet), to a first approximation both the forward Compton scattering of the γ-rays and the depth dependence of the neutron thermalization may be neglected. The effective area of our detector for 10.8 Mev γ-ray absorption[6] is 9 cm^2. The measured flux at 50 sec is thus $3.5/cm^2$-sec, $1.0/cm^2$-sec of which is attributable to the Br_{87} component.

$$\psi_\gamma = (1 - R)\ f\ E\ E'\ \Omega\ e^{-N X}\ \frac{1}{\tau}\ e^{-tK}$$

R = albedo - 0.67

f = delayed neutron fraction = 6×10^{-4}

E = capture probability to γ-emitting state = 5 percent

E' = probability of 10.8 Mev γ/capture - 11 percent

τ = decay time - 54.5 sec

$N X$ = 2-1/3 mean free paths {average path from neutron thermalization and capture.

$\Omega = \frac{.4}{4\pi}$ = .032 = angular factor for 10.8 MeV γ's

$\psi_\gamma = 5.6 \times 10^{-11}\ e^{-t/55}$ γ's/fission cm^2 sec from the Br_{87} fraction.

An approximate integration over the limits of the time corrected contours shown in Fig. 1, assuming a symmetrical east-west distribution, yields an effective area of $1.5 \times 10^5\ km^2$ for the maximum debris density measured at point A. Assuming a fraction F of 1 megaton of U_{235} fast fission products from the explosion spread over $1.5 \times 10^5\ km^2$, we have* a total of 10^{11} F fission/cm^2, or a 10.8 Mev γ-ray flux of $5.6\ F\ e^{-t/55}$ photons/cm^2-sec.

F = 0.45 for a preliminary estimate of the fraction of the debris in the southern conjugate area.

*Assuming 1 megaton = 1.5×10^{26} fissions.

REFERENCES

1. Sodama Matsushito, On Artificial Geomagnetic and Ionospheric Storms Associated with High Altitude Explosions. Jour. Geophys. Res. 64, 1149-1161 (1959).

2. Philip Newman, Optical, Electromagnetic, and Satellite Observations of High-Altitude Nuclear Detonations, Part I, Jour. Geophys. Res. 64, 8, pp. 923-933, (1959).

3. Reactor Hand Book Vol. 3, Interscience, 1962.

4. Groshev et al, Atlas of γ-ray spectra from Radiative Capture of Thermal Neutrons. Pergamon Press, 1959.

5. F. C. W. Colmer, and O. J. Littler, Pile Neutron Absorption Cross Sections. Proc. Phys. Soc. London, A63, 1175 (1950).

6. W. F. Miller and W. T. Snow, Rev. Sci. Inst. 31, 39 (1960), Energy Loss Spectra in NaI, also ANL-6318 (1961).

7. W. L. Brown, W. N. Hess, and J. A. Van Allen, Jour. Geophys. Res. 68, 605 (1963).

8. B. J. O'Brien, C. D. Laughlin and J. A. Van Allen, Geomagnetically Trapped Radiation Produced by a High Altitude Nuclear Explosion on July 9, 1962. Nature, 195, 939-943, (1962).

9. Carl E. McIlwain, Coordinates for the Mapping of Magnetically Trapped Particles, Jour. Geophys. Res. 66, 3681-3691, (1961).

10. D. C. Jensen and W. A. Whitaker, A Spherical Harmonic Analysis of the Geomagnetic Field. AFSWC; 1960, Jour. Geophys. Res. 65, 2500a (1960).

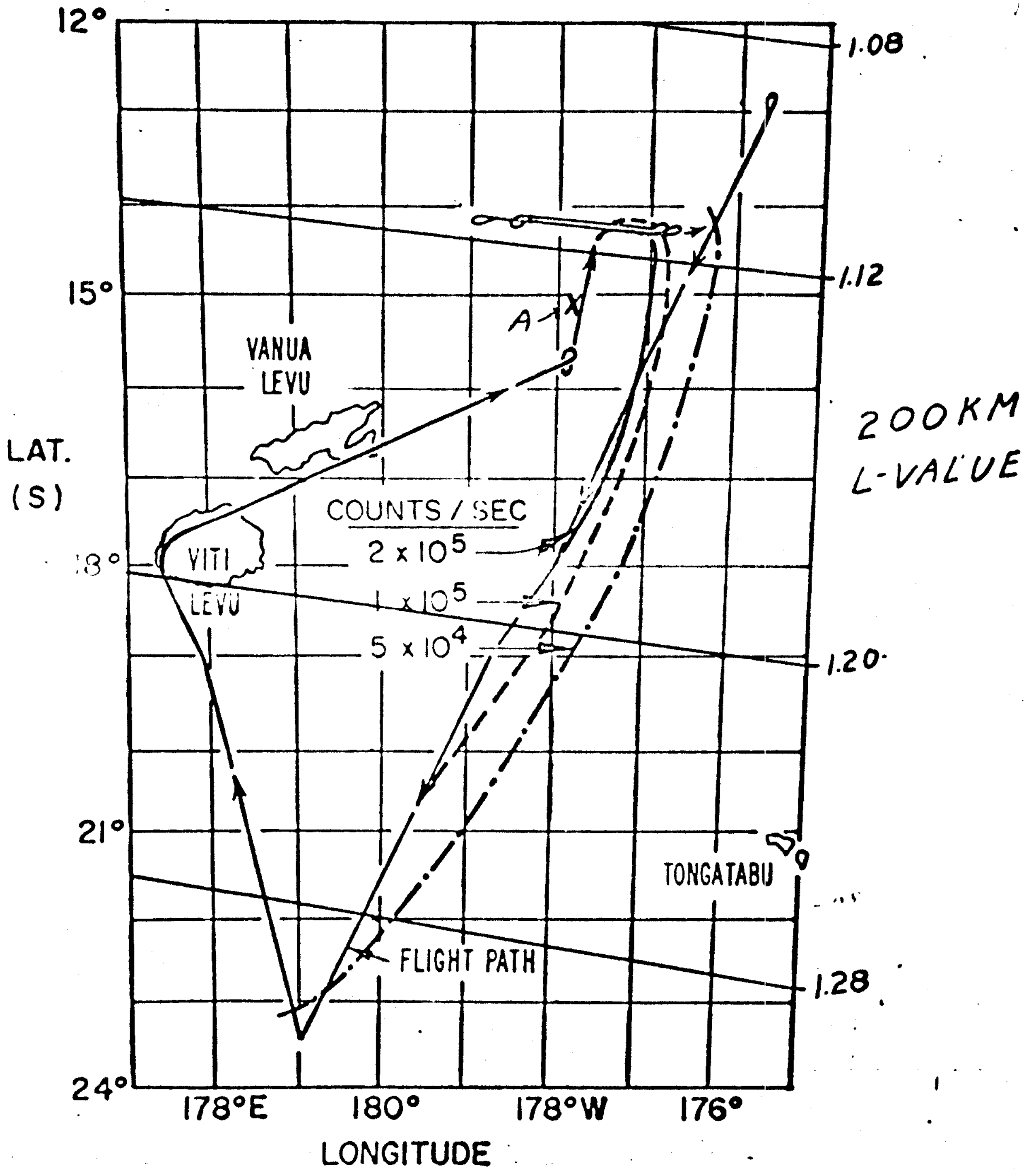
ACKNOWLEDGEMENTS

We should like to thank the personnel of DASA Project 6.10 for their assistance in this experiment; in particular credit is due to the Aircraft Commander, Major R. Creager, and to Captain K. Crookes, who piloted the KC-135 aircraft under extreme conditions of altitude and endurance, Captain E. Carr and Lieutenant F. Fisher, who navigated a rapidly changing flight plan with great accuracy, to J. Gauger and T. Barrett, for their cooperation and assistance in carrying out the experiment and to G. Gassmann for his support of this experiment and his planning of the flight path for the best combination of radiation and radio propagation measurements.

We are also indebted to O. Barlow, R. Swenson, and R. Blenz, for the design, construction, and maintenance of the equipment, to Major R. Dowd and R. Whidden for their assistance with the installation of the equipment in the aircraft and with logistical support in the field, and to G. Lentz, L. Littleton, A. Lukey, and E. Myles for the computer procession of the data. We have benefitted from discussions of the results with J. Carpenter, T. Stinchcom, and E. Stone.

We should also like to thank J. A. Simpson for his continued support and encouragement of this experiment, and for his advice throughout.

We thank J. Carpenter, and R. Giacconi, for the use of the preliminary gamma ray contours from their single channel gamma ray monitor.



12°
15°
18°
21°
24°
LAT.
(S)
178°E
180°
178°W
176°
LONGITUDE
1.08
1.12
1.20
1.28
200KM
L-VALUE
VANUA
LEVU
VITI
LEVU
TONGATABU
COUNTS / SEC
2 x 10^5
1 x 10^5
5 x 10^4
FLIGHT PATH
A

FIG 1

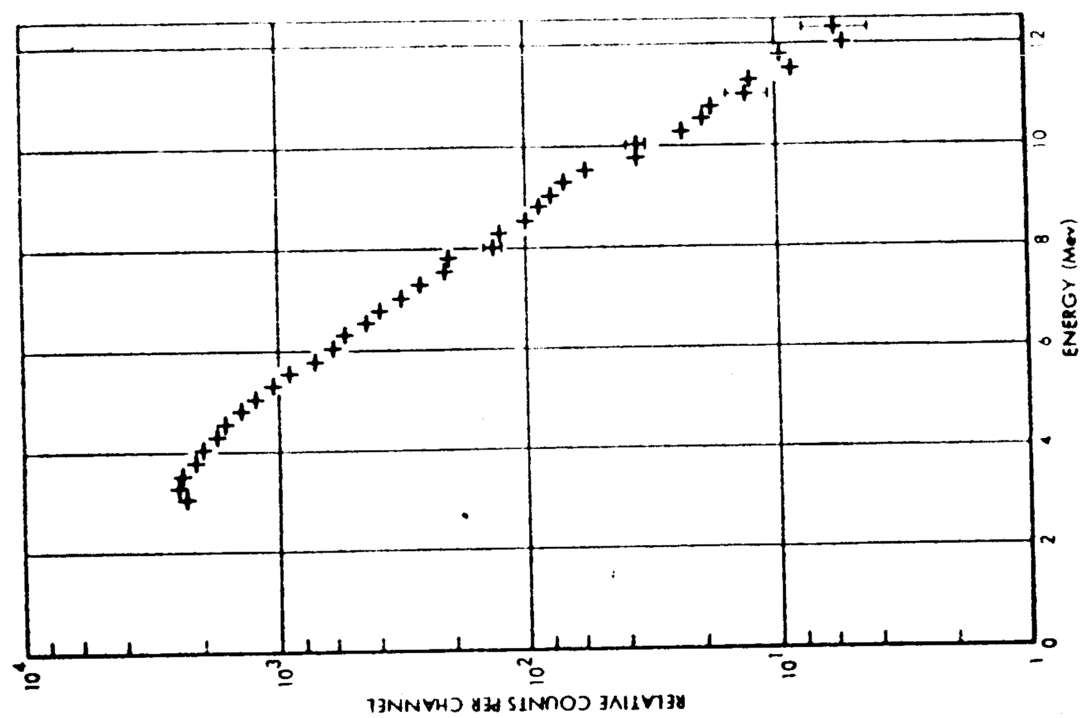


Figure 2 Time-Normalized Energy Spectrum at H+50 Sec

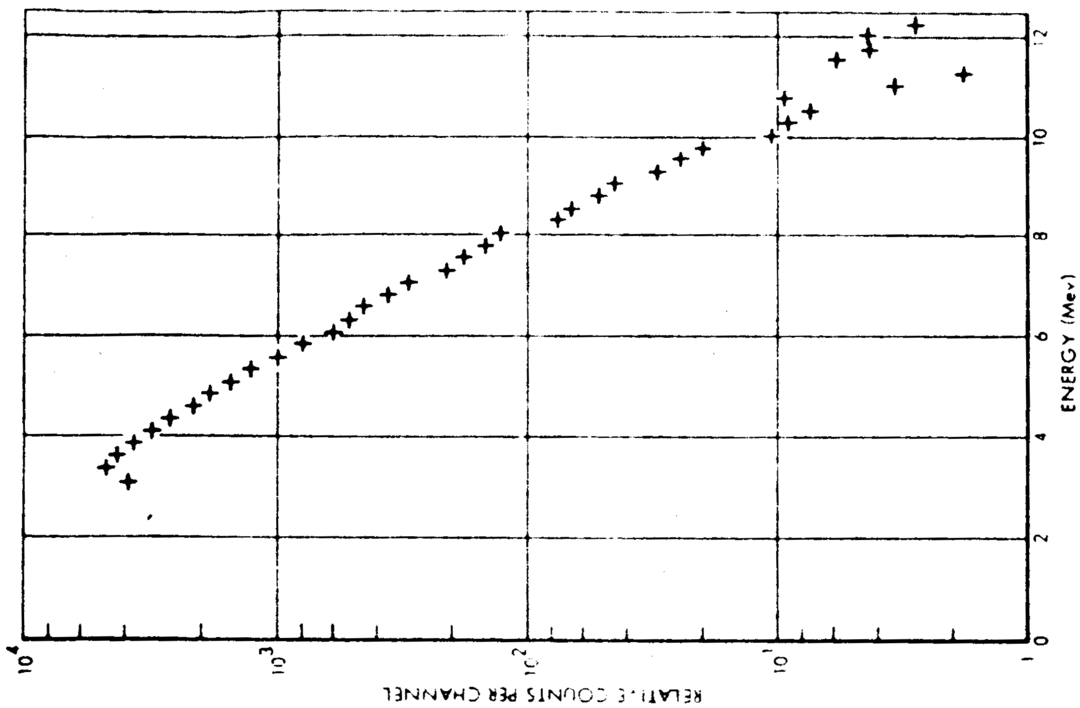


Figure 3. Normalized Spectrum at H+85 Sec

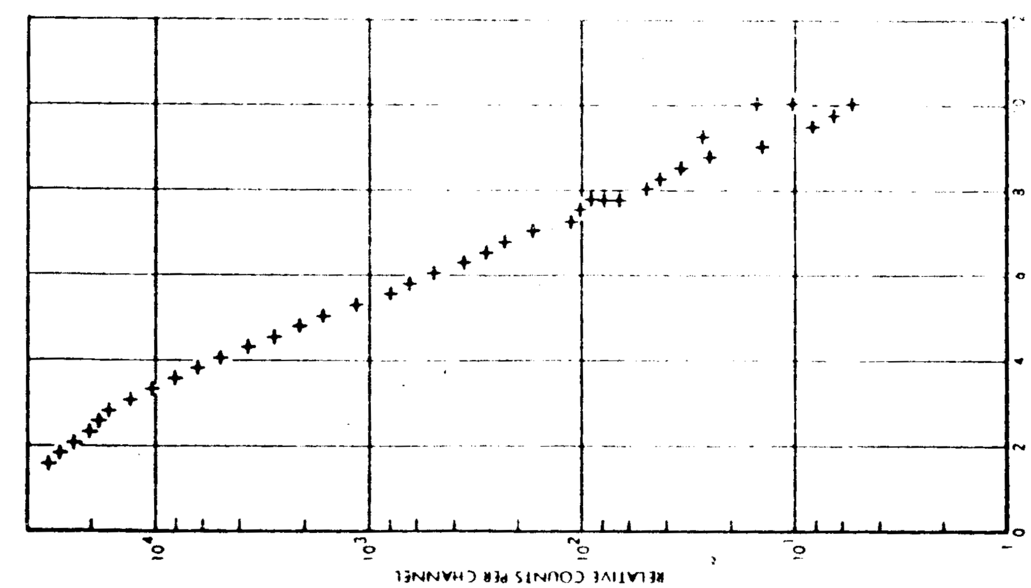


Figure 4. Normalized Spectrum at H+160 Sec

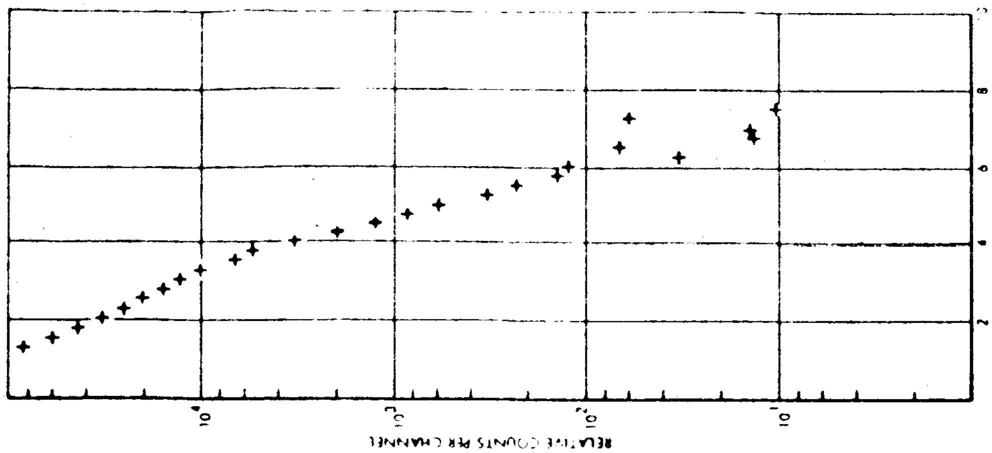


Figure 5. Normalized Spectrum at H+410 Sec

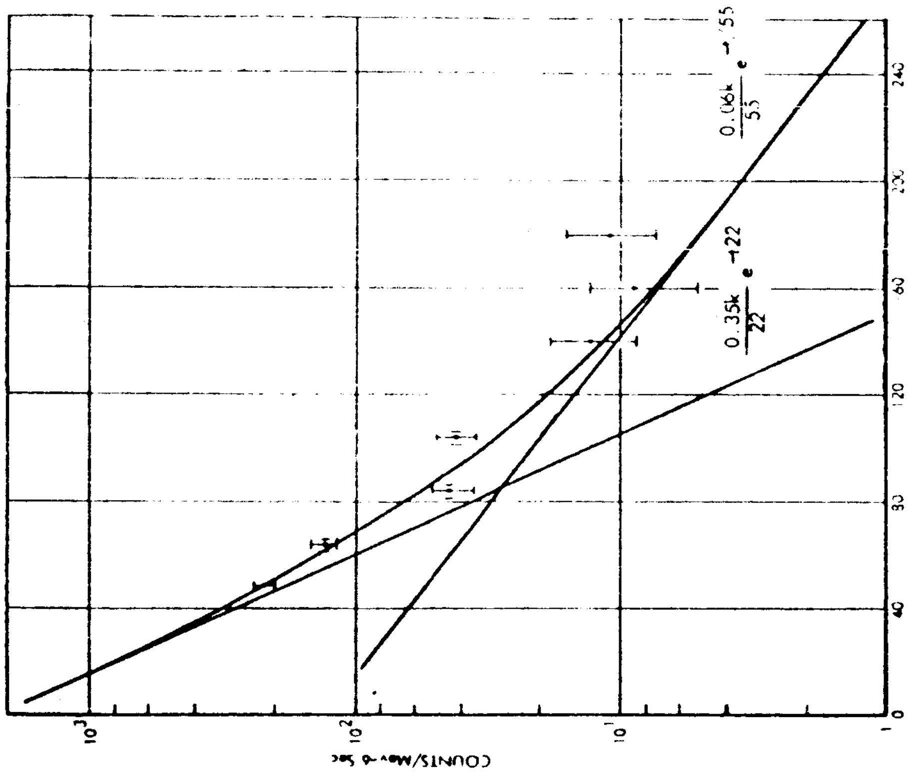


Figure 6. 10-11 Mev Gamma Rays Shortly After Blast

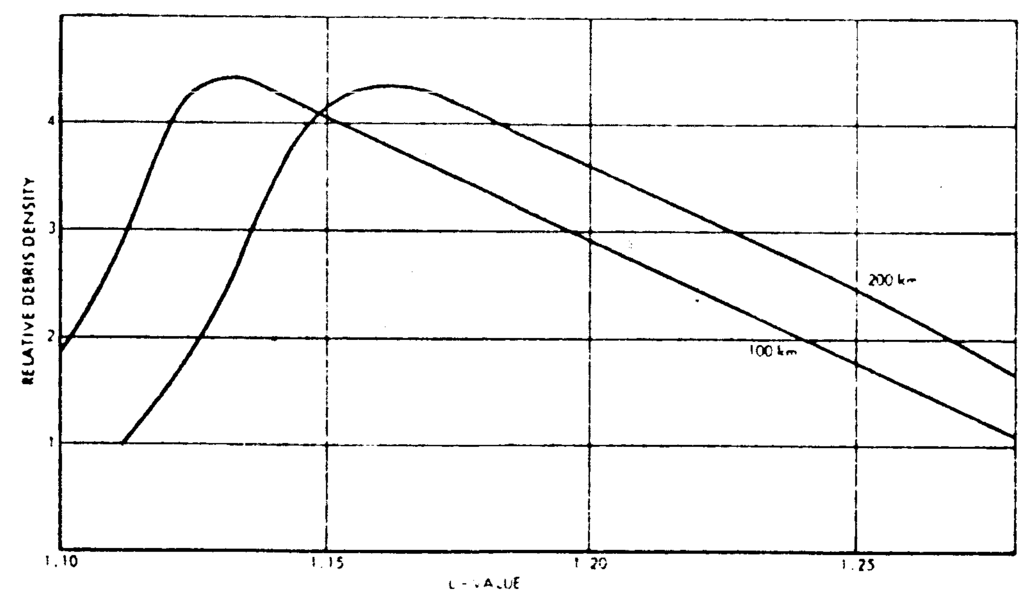


Figure 7. Debris Density Profile for Two Assumed Stopping Altitudes